A SIGNAL CONDITIONER AND ELECTRODE TECHNIQUE FOR NYSTAGMUS MEASUREMENTS

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BY

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SUMMARY PAGE

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THE PROBLEM

For the implementation of research programs concerned with the biophysics of the vestibular system, it was desired to measure and record nystagmic eye motions in response to stimuli produced by two devices: one, the Pensacola Human Centrifuge, a rotating unit capable of producing high-level linear accelerations, and the other, the Human Disorientation Device, a two axis rotator.

FINDINGS

An instrument was developed utilizing commercially available transistor preamplifiers which allows the simultaneous registering of horizontal and vertical nystagmic eye motions as derived from corneo-retinal potentials. The unit is capable of operating in the acceleration environment afforded by either stimulus device and can be calibrated and controlled from a remote operating station. A description is also provided of the surface electrode techniques utilized in conjunction with the instrument to obtain reliable nystagmus data.

AUTHOR

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Mr. A. C. Martin and Mr. C. L. Browning of the Medical Electronics Laboratory, who constructed the instruments and performed the evaluation tests.

INTRODUCTION

This report describes an instrument developed to implement vestibular research programs concerned with the quantification of nystagmic eye motions (2-4). The instrument, using commercially available transistorized preamplifiers, provides signal-conditioning circuitry for the simultaneous recording of horizontal and vertical nystagmic eye motions as derived from corneo-retinal surface potential measurements. The report outlines the circuitry of the instrument and states the performance in terms of its technical and operational characteristics, and describes the surface electrodes and associated techniques utilized by the authors for the nystagmus measurements.

The need for the instrument arose from the authors' interest in the investigation of the response characteristics of the human semicircular canals when exposed to vestibular stimuli produced by aircraft flight maneuvers and by two specific rotating devices in current use at this activity. One device, the Human Disorientation Device allows rotation of a subject simultaneously about two orthogonal axes with precise control of the angular velocity and angular acceleration occuring about either axis. The second device, the Pensacola Human Centrifuge, is capable of generating high-level linear accelerations based on centripetal force action, which, with the programming of controlled or random head movements of the subject can produce complex stimulation of each set of near-orthogonal semicircular canals.

For each device it was desired to record and measure the corneo-retinal potentials arising from nystagmic eye displacements occurring in the horizontal and vertical directions which would occur as a result of the angular acceleration stimuli applied by the device or produced by motions of the subject within the rotating environment. Because the subject station within each of these devices is physically separate from the control room area where the actual recording process takes place, the nystagmus signal-conditioning equipment must be installed on-board to minimize interference artifacts, and necessarily also be capable of operating in whatever force environment is generated by rotation of the device. The remoteness of subject-observer stations coupled with the desire for precise measurement of the nystagmus data also dictated a circuitry requirement for external control and calibration of the equipment.

The instrument developed to meet these requirements provides enough voltage amplification and impedance transformation for the corneo-retinal potentials to make negligible any 60 cps interference effects arising from the remoteness of the subject from the slip-ring connected recording station. It can operate in the force environment afforded by military aircraft, the Human Disorientation Device, or the Pensacola Human Centrifuge, and it allows the operator to enter remotely an input calibration signal to permit accurate setup of the recording equipments.

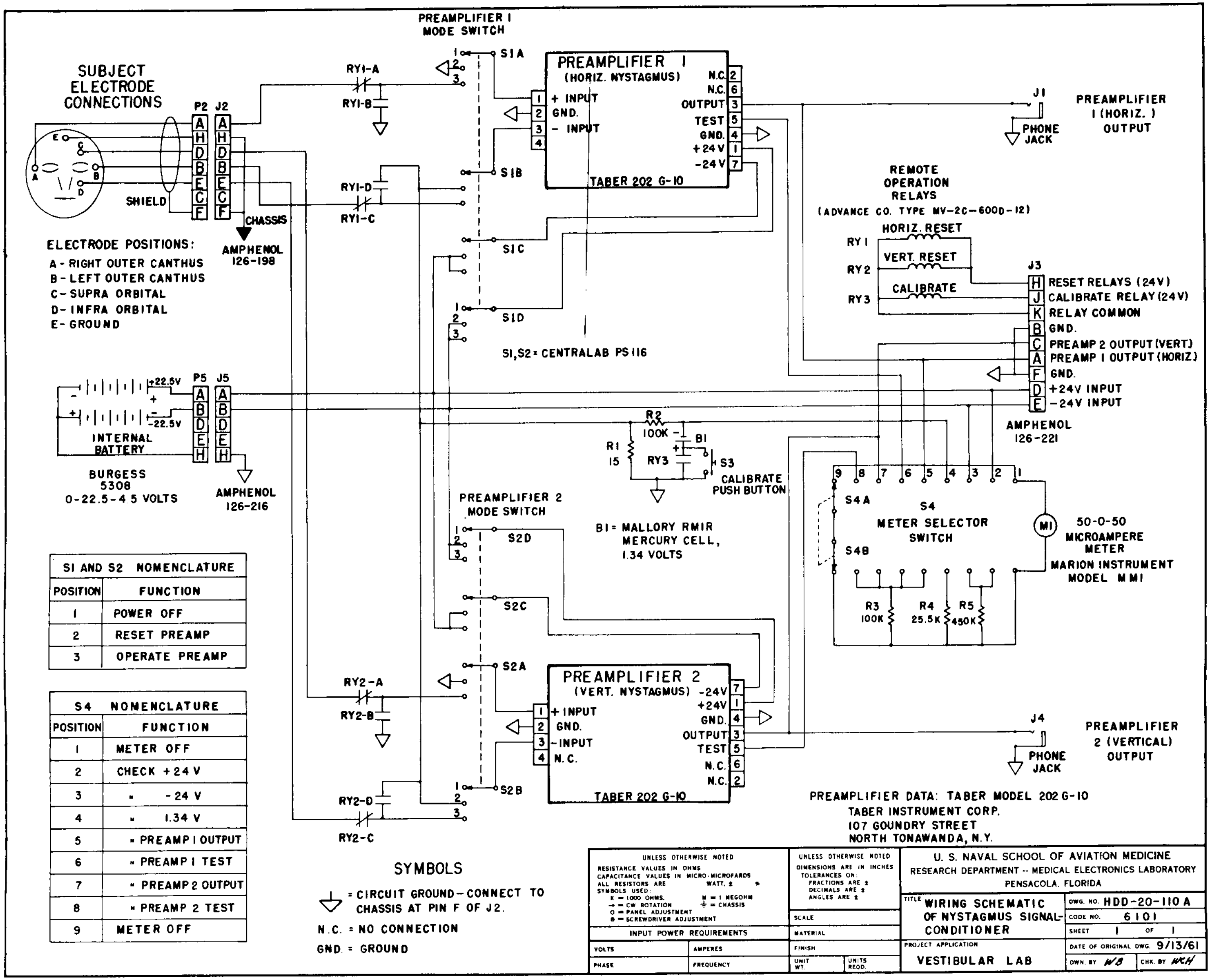

FIGURE 1

Schematic Drawing of Nystagmus Signal-Conditioner

INSTRUMENT DESCRIPTION

The basic elements of the instrument are two solid-state, miniature preamplifiers which provide both voltage amplification and impedance transformation for the dynamic changes occurring in the corneo-retinal potentials during exposure of the subject to nystagmus producing stimuli. One amplifier is associated with eye movements in the horizontal direction as described by the potential difference between surface electrodes placed at the outer canthi of the left and right eyes, while the second amplifier is associated with vertical eye motions as described by the potential difference occurring between similar electrodes placed in the supra and infra orbital positions about one of the eyes. These units are factory modified versions of an electrophysiological preamplifier (Taber Instrument Co., Model 202 G-10) designed originally for electrocardiographic measurements. The modifications were specified by this laboratory for its intended nystagmus applications so as to obtain a greater low-frequency response than that afforded by the standard electrocardiograph preamplifier.

Each of the temperature compensated transistorized preamplifiers incorporates differential input circuitry with high common-mode rejection properties and single-ended output circuitry to provide a system with a minimum voltage gain of 1000 and a low frequency response with a 1.5 second time constant. The output circuitry of each unit has an internal impedance of less than 150 ohms and can deliver an undistorted output voltage greater than 2.0 volts rms with the no-signal DC output level centered about zero volts. Each amplifier operates from a dual power source with nominal DC output voltages of plus-or-minus 24 volts with a current demand of less than 5 milliamperes from each source. Of particular importance to the intended applications of this instrument is the ability of each amplifier to withstand high G loads and vibrations extending to 40 G at 60 cps without any significant increase in noise level. Of equal importance for airborne measurements is the ability of each preamplifier to operate with a plus-or-minus 2 per cent gain stability over the 0 to 50 degree Celsius temperature range.

CIRCUITRY

The schematic wiring diagram for the instrument is given in Figure 1. Shielded cable connects the five surface electrodes to the device via receptacle J5. The two electrodes at the outer corners of the eyes are routed to the input circuitry of amplifier 1 while the two electrodes placed in the supra and infra orbital positions of one eye are routed to amplifier 2. The fifth electrode, mounted on the forehead, is connected to the chassis and serves to place the subject at the same ground or earth potential as that of the instrument. To permit operation of the device at its installation point, and to permit the independent control of either amplifier, two manually adjustable switches, S1 and S2, have been installed on the front panel.

Each of these switches has three positions, "Off," "Reset," and "Operate." In the "Off" position, sections S1A and S1B of switch S1 control the removal of the plus and minus operating battery voltages from amplifier 1. These operating potentials are supplied from a center-tapped 45 volt battery mounted inside the instrument case which is connected to the chassis circuitry through plug-receptacle combination J5. In the "Reset" position, S1 effectively shorts the two amplifier 1 input terminals together, thus allowing the operator to prevent amplifier overloads or attendant recorder galvanometer damage which might occur during the setup of an experiment. In the "Operate" position, S1 connects the two horizontally placed electrodes directly to the differential input circuitry of amplifier 1.

For the reset action, section S1C returns the plus input terminal of amplifier 1 directly to ground and section S1D returns the minus input terminal to ground through R1, a 15 ohm resistor. This resistor, in conjunction with R2 and a 1.34 volt mercury cell, allows a 200 microvolt calibration signal to be applied to the input of the amplifier whenever the momentary action pushbutton S3 is depressed by the operator or when the calibrate relay RY3 is energized from a remote operating station. When S1 is in the "Operate" position, the two electrode circuits are routed to the amplifier 1 input terminals via normally closed contacts of the Horizontal Reset Relay RY1 and switch sections S1C and S1D. Switch S2 and RY2 perform the same circuit functions for amplifier 2.

The single-ended outputs of amplifiers 1 and 2 are independently available at the front panel from phone jacks J1 and J2, respectively. The same outputs are also available on the nine-contact receptable J3 which is used when remote operation of the instrument is required. The 24 VDC coil circuits of the reset relays, RY1 and RY2, and the calibrate relay, RY3, are terminated at J3 to permit reset or calibrate action to be initiated at a remote control point. For operation of the instrument from an external battery source, the plus and minus 24 volt supply lines to the two amplifiers are also brought to J3.

To allow the output voltage level of the internal batteries to be checked and to aid in the initial setup and calibration of the instrument, a meter and associated selector switch have been mounted on the front panel. This combination permits the operator to measure the output voltage of the two plus and minus 24 volt supply batteries and the 1.34 volt mercury calibration cell. It also is used in the procedure for setting the DC output voltage of each amplifier to zero volts. This procedure involves adjusting a subminiature "Balance" potentiometer for zero voltage difference between the output lead and a test point (pins 3 and 5, respectively, on the output receptable of each amplifier) followed by the adjustment of a similar "Level" potentiometer to bring the potential difference between the output and chassis ground to zero. A "CMR" control is also provided on each preamplifier to provide the internal circuitry with optimal common-mode rejection properties. These are relatively long-term type adjustments and following their initial setup do not have to be changed unless circuit values of the components change significantly as a result of aging effects.

A ten-turn potentiometer is also available on the preamplifier to permit the voltage gain to be set to any value between 1000 and 2000. Since the electrical location of this potentiometer in the preamplifier circuitry results in a small reduction in the time-constant response characteristics as the voltage gain is increased, the gain is left at its minimum position for the nystagmus measurements.

Photographs of the front view of the instrument and its carrying case, along with a rear view of the chassis with the case removed, are shown in Figure 2.

EVALUATION TESTS

Two instruments, utilizing the described circuitry and components, have been completed and placed into operation. Evaluation data on the common-mode rejection and input resistance characteristics of the four preamplifiers installed in the two instruments are summarized in Table 1. To establish the frequency dependence of these characteristics, measurements were performed at 1, 10, and 50 cps. The common-mode data indicate that adequate rejection of in-phase signals is provided even at the 1 cps measurement frequency.

TABLE I

Common Mode Rejection Ratio and Input Resistance Characteristics as a Function of Frequency for the Four Nystagmus Preamplifiers

			Input - Resistance (ohms), K=X1000			
			Technique A		Technique B	
Preamp No.	Freq. (cps)	Common Mode Rejection Ratio	Between + Input and Ground	Between − Input and Ground	Between + Input and Ground	Between − Input and Ground
1	1	1800	66K	68K	67K	67K
1	10	2100	64K	68K	63K	68K
1	50	2700	65K	69K	65K	69K
2	1	1100	62K	61K	61K	61K
2	10	2250	63K	61K	62K	61K
2	50	2900	62K	61K	62K	61K
3	1	1000	72K	71K	70K	70K
3	10	2700	73K	71K	71K	71K
3	50	3000	72K	71K	71K	70K
4	1	1050	72K	72K	71K	71K
4	10	2400	70K	72K	71K	71K
4	50	2700	72K	72K	71K	70K

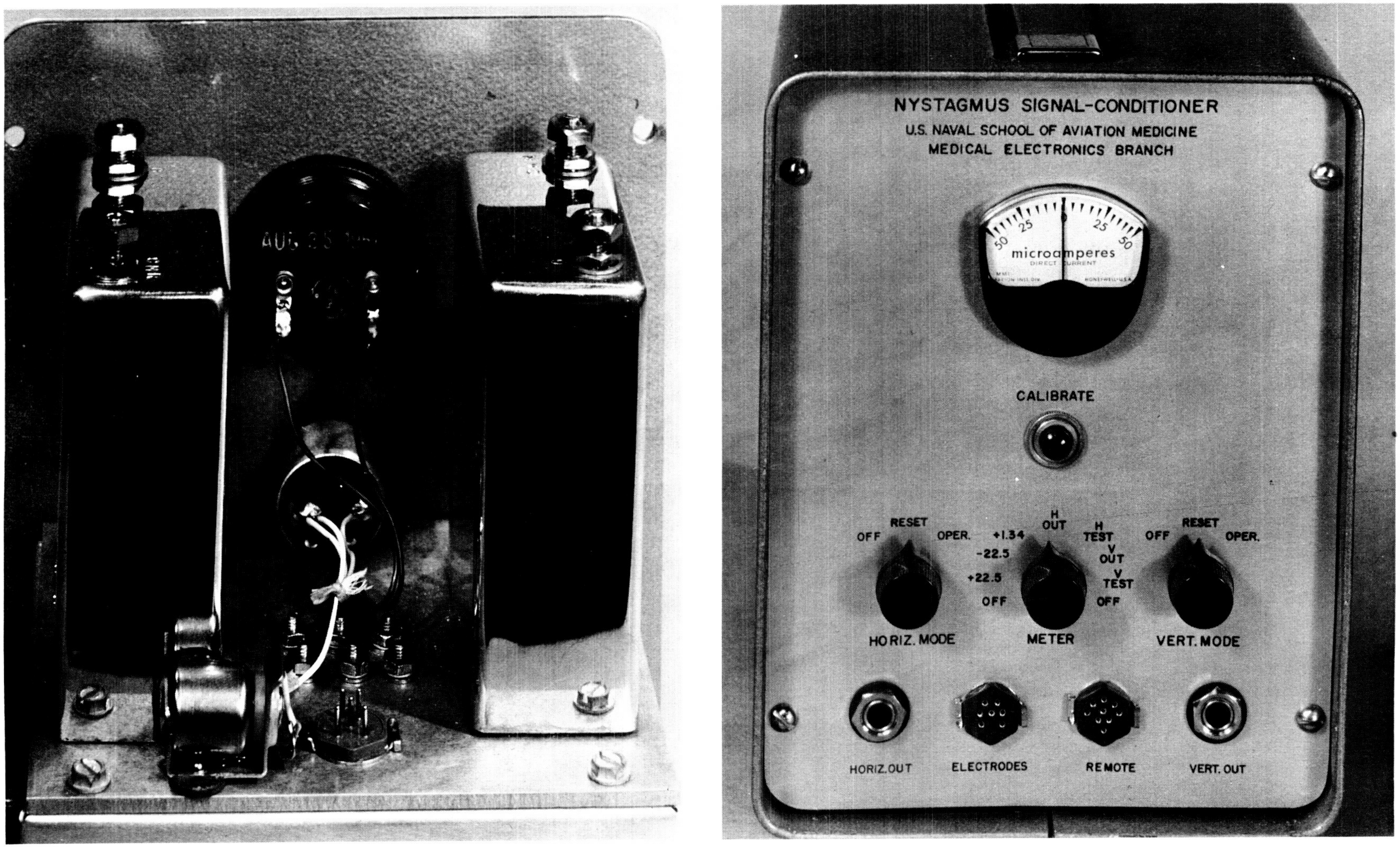

FIGURE 2

Front View (Left) of the Instrument Installed in its Carrying Case and Rear View (Right) with the Case Removed

The input resistance data shown in Table 1 were collected using two different measurement techniques. Technique A involved the conventional procedure whereby a variable resistance is placed in series with the driving source and amplifier input; the input resistance being equal to the value of the series resistor which decreases the amplifier output voltage to one half of the level obtained without the resistor. Technique B involved the substitution of a fixed 15,000 ohm resistor for the variable resistor and the calculation of the input resistance from the measured drop in amplifier signal level occurring when the resistor is placed into the circuit. The latter procedure, although lacking in absolute measurement accuracy, ensured that the high value of series resistance used in technique A did not alter the biasing requirement of the preamplifier input transistor network. As can be seen in Table 1, the data derived from both techniques are quite comparable and essentially frequently independent over the 1 to 50 cps spectrum.

Data describing the upper and lower cut-off frequencies where the voltage gain is equal to 0.707 of its mid-band value are shown in Table II for each of the four preamplifiers. The pass-band of each unit extends from about 0.08 cps to over 2000 cps. Since the upper cut-off frequency far exceeds that required for registering of nystagmic eye motions as derived from corneo-retinal potentials, external filtering is usually employed to minimize undesired muscle potential artifacts.

TABLE II

Frequency Response and Equivalent Input Noise Characteristics for the Four Nystagmus Preamplifiers

	Frequency Response (Half Power)		Equivalent Input Noise (Peak-to-Peak)	
Preamp No.	Lower Cut-Off Frequency (cps)	Upper Cut-Off Frequency (cps)	Shorted Input (Microvolts)	10K Triaxial Dummy Load (Microvolts)
1	0.079	2050	2.5	8.0
2	0.081	2025	3.5	10.0
3	0.08	2100	4.0	7.0
4	0.08	2050	2.5	8.0

Table II also summarizes the peak-to-peak equivalent input noise of each preamplifier with the input shorted and with a triaxial 10,000 ohm dummy load resistor bank. For the latter case, the two active input terminals and the single ground or common terminal of each amplifier were joined to an isolated junction point by three separate 10,000 ohm resistors. Although most measurement techniques use only two resistors, this triaxial resistor combination more closely approximates the operating conditions involved in three-electrode electrophysiological applications. It should be noted that these noise data are described in peak-to-peak values as measured from records displayed on an oscillograph with a frequency response extending from 0 to 125 cps. Specifically, they are not presented in rms terms since such descriptions are meaningless for electrophysiological applications unless the crest factor, and its time-variations, are adequately defined.

These data indicate that the characteristics of these preamplifiers are adequate for the specific applications described, although certainly minimal compared to what can be achieved by vacuum tube techniques which were necessarily precluded by the nature of the stimulus environment. Instruments which were constructed with the units have been in active use without malfunction for over eighteen months. A new preamplifier, Taber Instrument Co., Model 228-2, with improved input impedance, equivalent input noise, and low-frequency response characteristics is under evaluation for similar nystagmus application.

APPLICATION

A photograph illustrating one application for these instruments is shown in Figure 3. Here a subject with corneo-retinal potential electrodes

FIGURE 3

Interior View of the Human Disorientation Device Illustrating One Application of the Instrument

in place is shown seated in the capsule of the Human Disorientation Device. The nystagmus signal-conditioner is mounted on a hinged instrument support assembly located above and in front of the seated subject. The output signals from the signal conditioner are routed through a computer type patch panel installed immediately above the subject's head and then via the capsule slip rings to the remote recording station and operator's console.

Switches are provided at the console to permit remote resetting or calibration of the two preamplifiers. An automatic timer alternately energizes and releases the internal calibrate relay in one-second increments, allowing the operator to set the recorder gain to the desired level. A second set of switches on this console allows the operator to illuminate a visual target placed in front of the subject which permits the corneo-retinal potentials to be quantified in terms of microvolts output per degree of eye movement. This target provides, first, for subject fixation on a stationary central lamp to permit centering of the reference gage on the recorder chart, and, second, for alternating fixation on two sequentially illuminated lamps resulting in eye movements of plus and minus 20 degrees about a center reference line. Target lamps for both vertical and horizontal eye calibration are provided.

Typical nystagmus data as collected with this instrument for a specific research application (3) are shown in Figure 4. The constant frequency sinusoidal angular acceleration stimulus produced by the Human Disorientation Device is shown at the top of this figure while the nystagmic eye displacements produced by five different peak acceleration levels are shown immediately below. This figure also includes the related nystagmic eye velocity data as derived from a separate operational amplifier differentiator instrument.

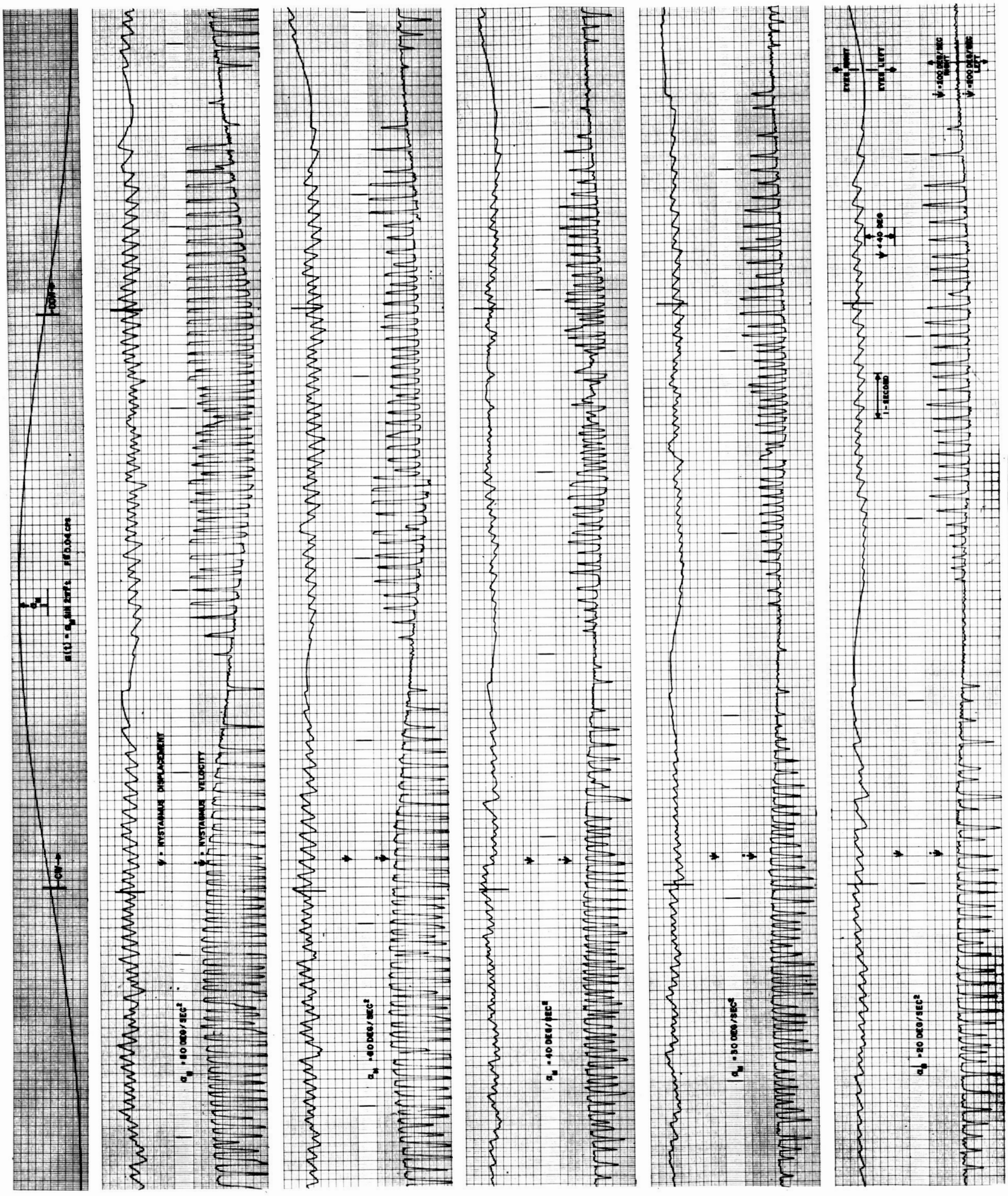

FIGURE 4

Typical Nystagmus Data Collected with the Instrument. (See text)

NYSTAGMUS ELECTRODES AND PROCEDURES

The function of this section of the report is to outline the procedures used by the authors to record corneo-retinal potentials derived from surface-placed electrodes. In direct contradistinction to the trend in current day literature, the authors make no claim that the electrodes and procedures herein described are revolutionary in concept or a panacea for recording ills. It is true, however, that rigid adherence to these procedures, i.e., attention to technique, has resulted in the consistent collection of reliable nystagmus data over a period of several years.

The electrodes proper are commercially available cup-shaped silver discs which were originally manufactured by electroencephalographic applications. For electrical connection, a flexible No. 30 AWG vinyl insulated cable composed of seven strands of No. 44 AWG pre-tinned, soft-drawn copper wire is soldered to the flat rear surface of the electrode. This connection is accomplished by fanning out the 1/16 inch exposed portion of the seven strands at right angles to the main body of the cable, taking care to use a minimum of solder at the junction. This junction along with a short length of connecting cable is completely covered with a thin coat of epoxy potting compound which cures in two hours at 140 degrees F.

When hardened, this coating gives the junction additional mechanical strength and prevents its inadvertent contamination with electrode paste or similar conducting solutions which could produce extraneous potentials as a result of electrolytic action. Since normal operational usage of the electrode always involves repeated bending of the connecting cable at this junction, the epoxy covering is further coated with a flexible neoprene potting compound to reduce potential breakage effects arising from cable flexion. To prevent contamination of the solder junction and to obtain a good sealing bond for each of the potting compounds, the related surfaces and materials are thoroughly cleaned with acetone or a similar agent before and after each assembly operation.

The end of the connecting cable leading to the input circuitry of the signal-conditioning preamplifier is terminated in either a miniature coaxial cable connector, a standard 0.053 inch gold-plated taper pin, or a multi-contact receptacle according to the requirements of the specified application. The essential characteristics of the finished electrode assembly are low mass, minimal thickness, and a connecting junction which is electrically sealed and mechanically reinforced. A photograph of the finished electrodes is shown in Figure 5 with pertinent construction techniques and materials summarized in Figure 6.

The methods and materials used to attach these electrodes to the subject are also outlined in Figure 6. Here the design goal was to establish good electrical contact between the inner metallic surface of the electrode and the skin surface of the subject for experimental periods ranging between one-half and eight hours. The basic material used to affix the electrodes is a moleskin-backed tape with good adhesion properties. Two tape configurations, shown as Units A and B in Figure 6, along with a polyurethane foam sponge, Unit C, are involved in the preparation.

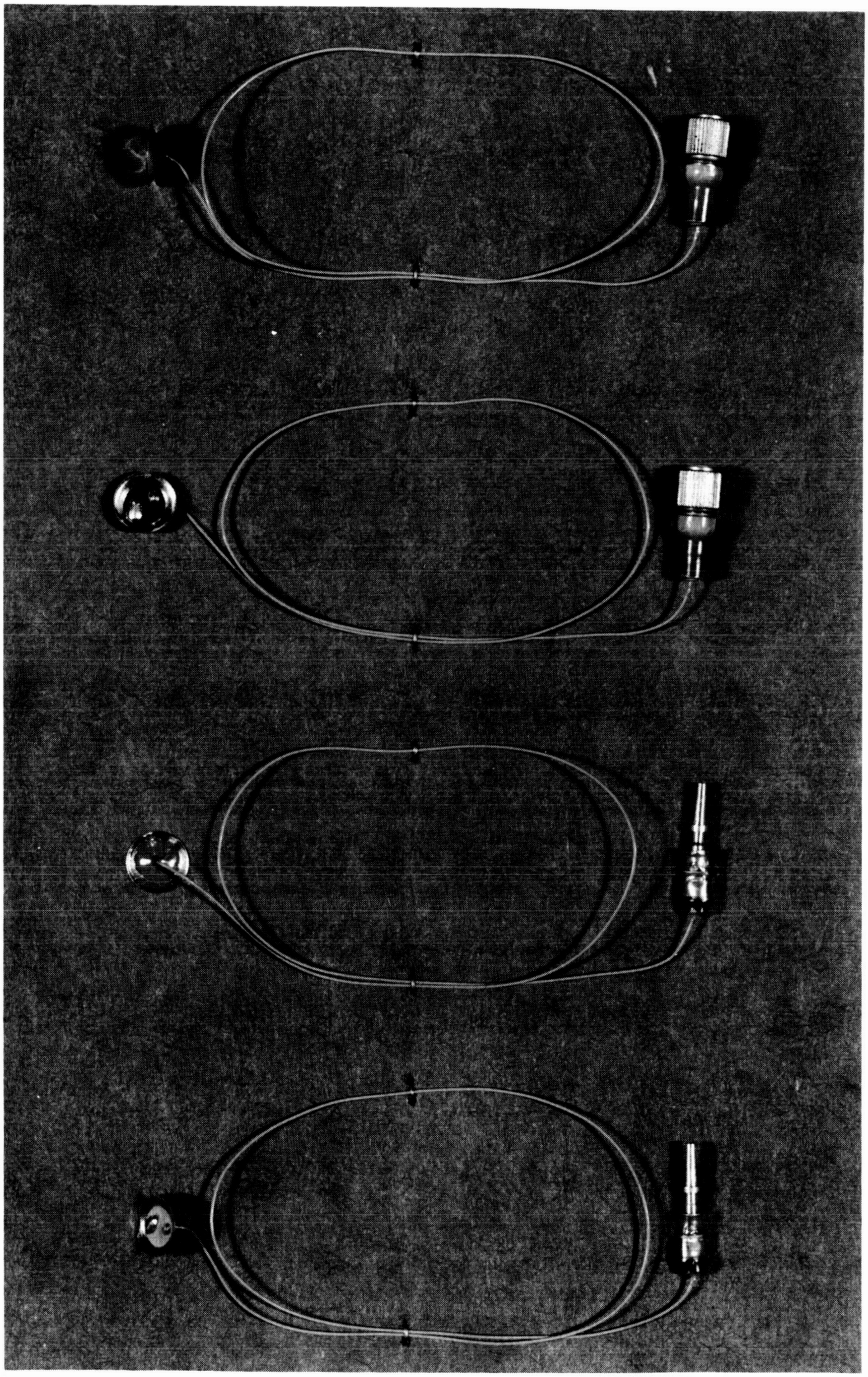

FIGURE 5

Photograph of the Nystagmus Electrodes Described in the Text

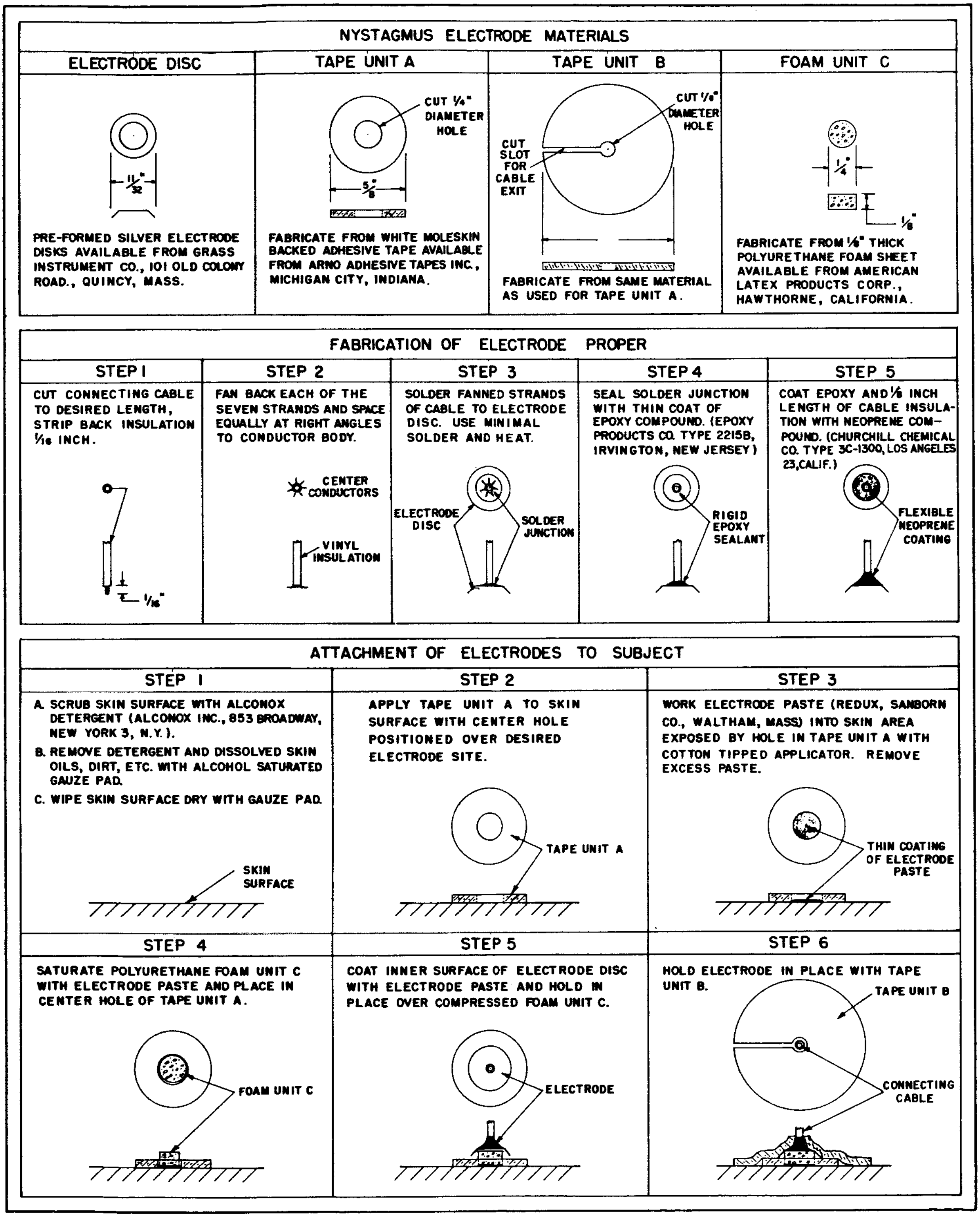

FIGURE 6

Materials and Methods of Construction and Attachment in the Nystagmus Electrode Technique

The skin area to which the electrode is to be attached is first cleaned with a conventional laboratory detergent solution which places most of the surface skin oils into solution. The detergent solution is then removed by wiping the skin surface with a gauze pad soaked in absolute alcohol, N. F. grade. After the skin surface dries, tape Unit A is applied at the desired electrode location. Electrode paste is then worked with a cotton-tipped applicator into the skin surface exposed by the circular hole precut in the center of Unit A. Next a polyurethane sponge disc, stored in fresh electrode paste in an airtight glass container to ensure saturation with paste, is selected and placed in this hole with stainless steel tweezers to avoid contamination. The electrode proper, with a light coating of electrode paste on its inner surface, is then centered in place on tape Unit B by slipping the connecting cable throuhg the radial slot to the small center hole provided for it. Finally, the electrode proper is brought into place covering Unit C and tape Unit B is pressed firmly into place with the aid of an ordinary tongue depressor to minimize potential contamination by the operator.

The function of tape Unit A is to prevent direct contact between the inner metallic surface of the electrode and the skin surface proper so as to minimize artifacts produced by large scale changes in interface resistance due to relatively small movements of the electrode. Actual contact between the electrode and subject is established only through electrode paste held by the polyurethane foam sponge. The depth of the electrode is such that this sponge is always held in compression so that the probability of a void occurring in this volume, and its attendant increase in skin resistance, is minimal.

Resistance between the outer canthus electrodes, as measured with a conventional multimeter, ranged from a mean value of 2600 ohms immediately after application to 2200 ohms about ninety minutes later in an unselected series of 33 subjects. The standard deviation in both cases was 1300 ohms and the change statistically insignificant.

After recording is completed, the electrode assembly is carefully removed and dismantled, the tape units are discarded, the sponge disc is returned to the storage container to renew saturation with paste, and the electrode proper is cleaned meticulously with the detergent solution, flushed with alcohol, and dried with cotton tip applicators, and stored between clean gauze sheets for further use.

It has also been found advisable, especially when repeated recordings are to be made on the same subject, to have the electrode sites carefully cleansed with mild soap and water, dried, and a light application of wool fat, USP grade, applied to the area. This procedure effectively eliminated the occasional appearance of what appeared to be a localized dermatitis at the electrode sites.

It should be noted that the electrode configuration under discussion is meant to be applied to the experimental situation wherein measurement of dynamic nystagmic eye displacements is desired; i.e., the corneo-retinal potentials generated between a given set of electrodes will be passed through an amplifier using AC or capacitive coupling. Although good low-frequency response is required from the amplifier, changes in DC level due to electrode polarization, contact potentials, et cetera will not produce excessive recorder baseline shifts if the time-constant of the changes is much longer than the time-constant characteristic of the recording amplifier. However, if it is desired to measure static eye displacements where an amplifier response extending to DC is required, then these electrodes and associated techniques will not be adequate. Instead, full attention must be given to all extraneous DC potentials which may be generated within the system as, for example, has been done by Ford and Leonard (1) in their thorough approach to the problem.

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